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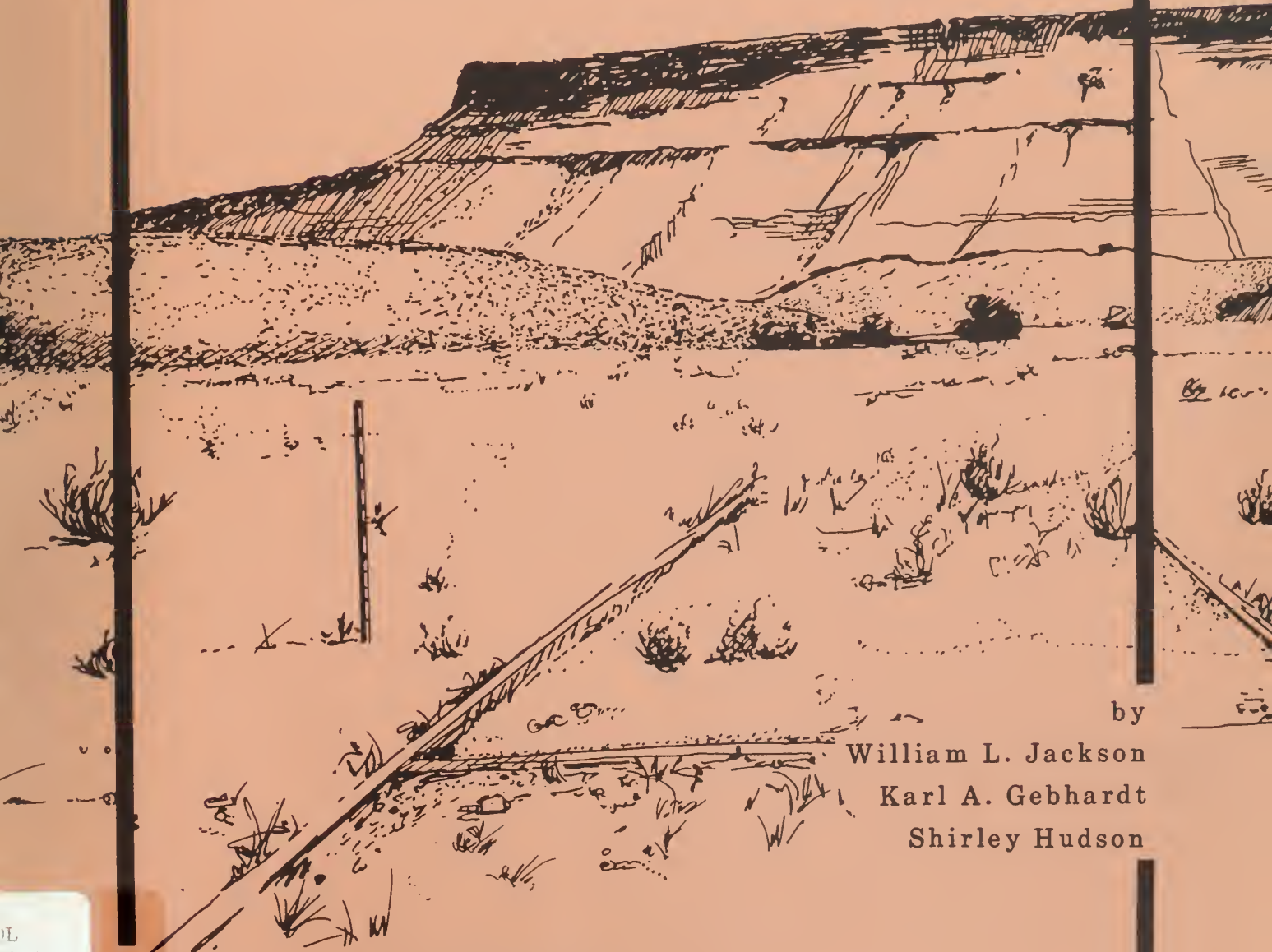


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**TECHNICAL NOTE 369**

# Considerations in Rangeland Watershed Monitoring



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Denver, Colorado

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WATERSHED MONITORING

by

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## I. INTRODUCTION

Monitoring is the orderly collection, analysis, and interpretation of resource data to evaluate progress in meeting management objectives. Rangeland watershed monitoring evaluates the achievement of soil and water resource management objectives identified in the Bureau of Land Management (BLM) Resource Management Planning (RMP) process. Rangeland watershed monitoring is used to determine what is happening to soil and water resources, why it is happening, and what adjustments in management might be required to meet soil and water resource management objectives. Thus, watershed monitoring is an integral feedback link in the RMP process.

It is useful to distinguish between monitoring and inventory. Inventories provide a broad quantification, characterization, or classification of resource conditions. While in some cases inventory data may be useful in establishing a base-line condition for monitoring, in most cases the sampling designs associated with broad inventories will be inadequate for quantifying the effects of management strategies on specific watershed values. Properly acquired, monitoring data quantifies the effects of land management strategies on watershed values, provides information for planning and watershed analysis, and validates or calibrates watershed models.

This technical note describes the components of a rangeland watershed monitoring plan, distinguishes between direct monitoring strategies (sampling) and indirect monitoring strategies (modeling), describes common watershed monitoring techniques, and discusses statistical considerations in sampling designs and data analysis. It also describes some monitoring principles and concepts, but does not prescribe specific monitoring programs. Monitoring programs will always have to be tailored individually to address the issues, management objectives, and conditions at the site of interest. Thus, careful analysis, planning, and judgment by the resource professional is integral to the design of watershed monitoring programs.

## II. BACKGROUND

The RMP process is designed to be issue-driven. Resource management issues are identified and analyzed early in the planning process. Management objectives are established and alternative management strategies are evaluated. Management objectives are achieved through implementation of specific activity plans. Soil and water resource management prescriptions may be incorporated into plans associated with management of other resource activities such as livestock grazing or wildlife management. If the watershed issue is highly significant and untreatable through other activity plans, specific watershed activity plans are prepared. Thus, watershed monitoring may involve evaluating the achievement of watershed objectives as part of other activity plans or achievement of specific watershed activity plan objectives.

### Rangeland Watershed Processes and Issues

Depending on the specific issue, a wide range of watershed processes may be the subject of monitoring programs. Rangeland watershed management issues occur when beneficial resource uses are impacted, or may be impacted, by manageable sedimentation and hydrologic processes. While certain water quality issues relating to salinity, nutrients, and bacteria are sometimes considered watershed management issues, they will not be discussed in this technical note.

Manageable upland sedimentation processes include rill and interrill erosion. Manageable instream sedimentation processes include channel bank erosion, incision, deposition and aggradation, and sediment transport. Issues related to those processes are diverse and include such things as reduced forage production, poor seed germination, lowered riparian water tables, changes in channel conditions, reductions in aquatic habitat, decreased flood flow capacities, increased reservoir siltation, and increased treatment costs to water users.

Manageable hydrologic processes which affect the volume or timing of runoff include infiltration, surface storage, interception, channel capacities, and both upslope and instream resistance to flow (sometimes referred to as "roughness"). Issues related to hydrologic processes include availability of soil water for plant growth, water supply for both instream and off-site uses, flood damage, stream channel maintenance and channel quality, sediment transport, and water quality.

### Common Watershed Management Techniques

Vegetation cover is usually the most important management variable influencing runoff and erosion rates on rangelands. Therefore, vegetation management, either directly through vegetation manipulations or indirectly through the design and implementation of livestock grazing plans, is a common rangeland management technique. A common watershed monitoring objective is to determine whether scientifically-designed grazing systems implemented through allotment Management Plans achieve vegetation-cover objectives. Assumptions about the relationship of cover (or some other vegetation variable) to runoff, erosion, stream channel conditions, etc., are also tested as part of watershed monitoring programs.



In situations where watershed condition is so severely degraded that natural recovery will be inefficient, mechanical land treatments and structural alternatives may be the most effective runoff and erosion control techniques (Jackson, et al. 1985). Monitoring programs may be designed to quantify the extent and duration of benefits achieved through mechanical land treatments. Monitoring of structures may involve the monitoring of structure integrity and function as well as the achievement of both on-site and off-site management objectives.

### III. WHEN TO MONITOR

In some situations, monitoring may be required by law or regulation. However, in the vast majority of rangeland situations, managers must decide when or what to monitor based upon the need for additional information for responsible management. Generally, the decision to monitor should be based on a thorough analysis of watershed condition including existing and potential resource values, resource-use conflicts, knowledge or information gaps, management costs, and applicable legal requirements.

When well-evaluated management prescriptions are applied to areas with low watershed values and no major resource-use conflicts, formal watershed monitoring may not be required. Instead, informal assessments by professional staff may be sufficient management feedback. However, when intensive management prescriptions address issues involving high watershed values or severely conflicting resource uses, and when a great deal of uncertainty exists about the likely effectiveness of the management action, well-designed monitoring programs may be required.

In considering when or what to monitor, it is also useful to distinguish between highly site-specific management issues, and more generalized management issues. When management issues are highly site-specific, monitoring may have to be tailored to each individual situation. However, where monitoring addresses general management strategies, coordinating monitoring programs between field offices insures that the information collected will resolve the overall monitoring question. In this case, representative management units should be selected for monitoring and uniform methods and designs employed.

#### IV. ESTABLISHING MONITORING OBJECTIVES

Watershed monitoring programs should answer the question, "Has the watershed management objective been achieved?" Thus monitoring objectives can be formulated as testable hypotheses regarding the achievement of management objectives. Also, the monitoring program should allude to why the objective was or was not achieved.

To properly formulate a monitoring objective, clear descriptions are required of (1) the prescribed management activity, (2) the affected resource, (3) the processes or variables which the management activity will influence, and (4) the "indicator" processes or variables which will test the attainment of the management objective. For example, the management objective may be to reduce upland soil loss by one ton per acre per year. The prescribed management activity may be a rest-rotation grazing system. The affected resource is the on-site soil resource. Management is attempting to influence raindrop splash erosion and rill and interrill erosion caused by reduced infiltration and increased surface runoff. Because an available validated model interprets vegetation cover in terms of soil loss, percent vegetation cover is selected as the "indicator" variable which will be tested to evaluate the achievement of the management objective. Had the cover vs. soil-loss model not been available, annual soil loss from 72 ft. plots may have been selected as the "indicator" variable. In other words, the indicator variable and the influenced processes may, in some situations, be the same.

The monitoring objective can now be formulated in terms of the management objective, the management activity, and the indicator variables. In the upland soil-loss example where vegetation cover was selected as the indicator variable, the monitoring objective might be: "To determine that a rest-rotation grazing system increases vegetation cover by X percent over the cover associated with the present continuous grazing system." In any case, the monitoring objective should be stated as concisely and quantitatively as possible. A well-formulated objective should clearly define testable hypotheses and lead directly to appropriate methods and sampling/study designs.

## V. WATERSHED MONITORING PLANS

Monitoring plans help guide the formulation and implementation of formal watershed monitoring programs. A monitoring plan provides a clear, concise strategy for achieving the monitoring objective. While monitoring plans may be brief, and included as part of resource activity plans, they should always contain the following items:

1. Statement of the Management Problem: The problem statement should include brief descriptions of the management issue, the management action, and the affected resource values.
2. Monitoring Objective: Formulating monitoring objectives is discussed above. In general, monitoring objectives are formulated in terms of the management objective, management activity, and indicator variables. Testable hypotheses should be formulated at this point.
3. Methods: Monitoring methods, including procedures, equipment, sampling techniques, and sample handling and analysis techniques, should be described or referenced.
4. Data Acquisition Design: The data acquisition design may involve a sampling design for direct data acquisition programs, or an input data acquisition program, including data sources, for indirect monitoring programs. Direct monitoring sampling designs need to consider required significance levels, sampling location and frequency, useful co-variables, and improvements to be gained by blocking, nesting, and stratification. An input data acquisition program which relies on existing available data should identify the data source, its availability and reliability, and any required format modifications. When the watershed monitoring program relies on data collected as part of other resource monitoring programs, the watershed specialist needs to ensure that the data collected meet the requirements of both monitoring programs.
5. Data Analysis Plan: The data analysis plan identifies the specific techniques and procedures to summarize and analyze monitoring data. For direct monitoring data, this may involve identification of appropriate statistical or numerical techniques. For analysis schemes relying on analytical models, the specific model should be identified and its application in data analysis described.
6. Data Interpretation and Report Plan: Data analysis provides a numerical or statistical summary of monitoring results. However, the meaning of those results from a management perspective may require additional interpretation by professionals and resource managers. For example, a statistical analysis may show a highly significant 0.1 ton per acre per year increase in soil loss resulted when the management objective was to not increase soil loss. However, from an overall resource perspective, it could be concluded that an increase that small is not important and that the management program has accomplished its objective. In any case, all results, interpretations, conclusions, and recommendations should be reported to management in writing upon completion of a monitoring program and at interim periods as may be required. The reporting plan should be described in the overall monitoring plan.
7. Implementation Plan: The implementation plan provides the required schedules, tasks, and budget required to implement the monitoring program.

## VI. DIRECT AND INDIRECT MONITORING CONCEPTS

As indicated above, monitoring objectives are formulated in terms of the prescribed management activity, the affected resource, the processes or variables to be influenced by management, and the indicator processes or variables which will be used to test the attainment of management objectives. Monitoring can be accomplished by

(1) direct monitoring: directly measuring the process or variable to be influenced by the management action, or

(2) indirect monitoring: measuring the effects of management on an indicator variable or variables and interpreting the effects on indicator variables in terms of the process or variable of interest to management. The interpretation step is usually accomplished by using descriptive or analytical models.

While directly monitoring key rangeland watershed processes is the most accurate and definite way of determining management effects on those processes, adequate sampling programs may be expensive and logistically difficult to implement. When direct sampling programs are scaled down to meet budget and manpower constraints, precision and statistical confidence is sacrificed. Thus, a reasonable alternative may be to identify appropriate indicator variables which can be more easily sampled and to interpret or translate information about the indicator variable into information about the variable of direct interest to management.

The interpretation process adds an additional source of error to the analysis. However, this can be compensated for, in part, by the improved precision associated with sampling an indicator variable as opposed to monitoring directly the process or variable which is the subject of a management action.

Models used in the interpretation process in indirect monitoring may be descriptive models, empirical models, or physically-based process models. In rangeland watershed management, most commonly used models are, to a large extent, empirical. The differences are mostly related to the extent to which sub-processes are handled individually, and the spatial scales to which the models are applied. Process-based, distributed parameter models are usually data-intensive and time-consuming to apply. Lumped-parameter, or "black-box" models are often simple to apply, but may not adequately account for all the variables of interest. Model accuracy tends to be highly dependent upon how well model assumptions fit the conditions at hand and how well the model has been tested and validated for the area where it will be applied.

Thus, an initial decision in designing a monitoring program is whether to use direct or indirect monitoring technologies. The decision will be based upon sampling considerations, costs, and the accuracy and availability of adequate interpretive models. In all cases, the approach selected should provide sufficient information to meet the monitoring objective.

## VII. DIRECT MONITORING STRATEGIES

Direct monitoring quantifies or measures the process or variable of primary interest to management as part of the monitoring program. For example, if soil-loss is the variable of concern to management, then direct monitoring would directly measure soil-loss rates on the site of interest. If infiltration is the process of concern to management, then monitoring might involve the direct measurement of infiltration rates on the site of interest. Finally, if stream discharge, water quality, or downstream sediment yields are the variables of concern to management, monitoring would involve the instream measurement of those processes.

Most common rangeland watershed processes present special problems from both a sampling and logistical standpoint. From a sampling standpoint, processes such as soil-loss, infiltration, stream discharge, suspended sediment transport, and stream channel erosion are complex processes exhibiting a great deal of variability in both space and time. A sampling program which fails to account for and quantify that variability will lack sensitivity to management changes. From a logistical standpoint, most commonly accepted techniques for sampling sedimentation and hydrologic processes are both equipment and labor intensive, and not conducive to the sampling intensities required to adequately quantify processes.

Direct monitoring strategies are most easily classified as upslope plot (and transect) studies, and instream discharge and sediment transport studies. Monitoring techniques which utilize plots or transects are amenable with the sampling principles of randomization, replication, and control, and can thus effectively detect the effects of management activities on upslope watershed processes. Instream sampling techniques are well developed and provide an integrated measure of total watershed response at a point over time. However, in rangeland settings, instream monitoring may not be amenable to control, so changes in runoff or sediment transport may be difficult to attribute to management.

A third direct monitoring strategy, channel geometry surveys, provides a long-term integrated measure of watershed response over time, at a point, and is somewhat less difficult, logistically, than discharge and sediment transport studies. Channel geometry studies are best suited to alluvial or self-formed stream channels, and--like plot studies--are compatible with the sampling principles of randomization, replication, and control.

### Upslope Runoff and Erosion Studies

The use of bordered plots for the direct measurement of surface runoff and soil loss from rangelands is thoroughly described in Bureau of Land Management Technical Note 368 (Jackson, et al., 1985). Plots are constructed so that all runoff and soil loss from them can be collected and measured. Runoff and erosion plots are most easily used for measuring annual runoff and soil-loss rates, but may be instrumented to record storm-period or instantaneous runoff and soil-loss rates. While there are no standard sizes for runoff plots, soil-loss plots should generally be at least 35 ft. in length, and preferably 72.2 ft. in length (USDA, 1981). In addition to providing direct monitoring data, data from soil-loss plots can be used to validate common soil-loss models, such as the Universal Soil Loss Equation (Wischmeyer and Smith, 1978).

Plots have certain advantages from a sampling standpoint in that they can be randomly located, replicated (i.e., at least two plots per treatment), and controlled. Control plots are generally located in an enclosure, or on an untreated area, at the selected monitoring site. The disadvantages to plots are (1) numerous plots are required to characterize the spatial variability within a given allotment, range-site, or small watershed, (2) upslope plot response to management activities is difficult to interpret in terms of instream or downstream processes, when those processes are of primary concern to management, and (3) the number of events required for suitable analysis may limit the plot's usefulness because of time constraints.

Depending on the variables or processes of interest to management, other upslope monitoring strategies are available which possess similar sampling attributes similar to plots. They include erosion pin surveys (soil loss), erosion net studies (soil loss), infiltrometer studies (infiltration capacities), and large-plot rainfall simulator studies (apparent infiltration capacities, soil-loss index). As with all monitoring programs, the proper selection of a monitoring technique will depend on the monitoring objective, site conditions, and budgetary and manpower constraints.

### Instream Discharge and Sediment Transport Studies

The design of instream watershed monitoring programs is well described by Ponce (1980), and guidelines for the collection and analysis of sediment data are provided by Williams and Thomas (1984). Instream monitoring programs involve the collection of discharge and suspended sediment concentration data within the context of a basic study design.

Instream sampling stations generally provide a continuous measurement of stream discharge and periodic measurements of suspended sediment concentration. Suspended sediment is sampled either by hand on a predetermined schedule or automatically using programmable pumping samplers. Whereas instantaneous discharge is usually measured accurately, the quality of suspended sediment measurements depends upon the method used (point or depth-integrated) and the sampling frequency. A common analysis method is to develop a regression relationship between instantaneous discharge and suspended sediment concentration.

The key to effective instream monitoring is carefully identifying the variable or process of interest to management, and then developing a sampling design and data analysis program which will quantify the effects of management.

Discharge variables of interest to management include peak or design-flow discharge rates, seasonal low-flow discharge rates, and annual or seasonal water yields. Sediment transport variables of interest to management include suspended sediment concentrations and total sediment yields. Sediment yields may be measured directly using reservoir surveys but are more commonly calculated from discharge and sediment concentration data. Bedload sediment yields may be sampled by a variety of techniques, but are most often determined indirectly using bedload transport equations or by compensating for the "unmeasured" load in suspended sediment transport calculations (Graff, 1971).

Since instream sampling techniques are often not amenable to sampling designs involving randomization, replication, and control, several other study designs are usually recommended for instream monitoring programs (Ponce, 1981). Common study designs include paired watershed designs, upstream-downstream designs, and single-station pre- and post-treatment designs. Both the paired watershed and single-station designs require sampling both prior to and after applying the management action to be monitored. The upstream-downstream design assumes that the sampling station upstream of the management treatment represents the "pre-treatment" condition, and the station downstream of the management treatment represents the "post-treatment" condition. For the one-station design, pre- and post-treatment statistical comparisons would be made by comparing means of the measured variables or regression lines of developed relationships (e.g., discharge vs. suspended sediment concentration). For the paired or upstream-downstream designs, statistical comparisons can be made by comparing paired-station regressions. Ponce (1981) recommends a paired station approach because it can account for year-to-year variability caused by climate and hydrology.

Rangelands present special problems for paired station instream sampling designs. Paired watershed designs are often not possible when summer convective storms produce high streamflow conditions, because most convective storms are highly localized and will not be similar over two separate watersheds. Upstream-downstream designs are made difficult by the dispersed nature of livestock grazing--the most common rangeland land use. It is difficult to locate upstream and downstream sampling stations on relatively homogeneous stream reaches.

Whichever instream monitoring design is selected, a great deal of thought needs to be given during the planning stage to data analysis procedures and the interpretations various data analysis results will have regarding management effects.

### Channel Geometry Studies

In alluvial or self-adjusting stream channels, channel hydraulic geometry variables, including width, depth, slope, sinuosity, bed sediment sizes, and resistance to flow all adjust to local hydrologic, geologic, and vegetation conditions. Thus, every channel assumes a unique set of geometric and hydraulic characteristics in response to its watershed condition. While there are no standardized methods of monitoring or interpreting hydraulic geometry, many studies document changes in hydraulic geometry in response to land use (e.g., Lyons and Beschta, 1983; Platts, 1981).

Collecting and analyzing channel cross-section data is discussed in Parsons and Hudson (1985). There is also evidence that other morphological features such as pool-riffle sequencing, sinuosity, and bed material composition may be useful monitoring variables (Jackson and Beschta, 1984; Beschta and Platts, 1985). Because monitoring using channel geometry methods is a relatively new technique, monitoring programs which utilize these techniques should be designed with great care. The roles and interactions of morphological features at a given site should be analyzed, controls should be identified, and a careful data analysis and interpretation plan should be developed so results can be interpreted in terms of management effects.



## VIII. INDIRECT MONITORING STRATEGIES

Vegetation cover is the most important management variable influencing runoff and erosion rates on rangelands, and most common rangeland watershed management techniques influence vegetation cover. Cover may be defined as canopy cover, foliar cover, basal area cover, or point cover (USDI Bureau of Land Management, 1985b). It is important to clearly define cover and the method used for measuring cover when using it as an indicator variable. Since vegetation cover is relatively easy to monitor (USDI Bureau of Land Management, 1984) compared to most watershed processes, it follows that any analytical tools which relate vegetation cover to such processes as runoff, or soil loss, are useful watershed monitoring tools. A number of such models are currently available and include both simple lumped-parameter empirical models and more complex, process-driven systems models. Models commonly available for rangeland watershed monitoring programs are described below.

When selecting a model for a monitoring program, carefully consider the objective, model assumptions and data requirements, and the extent to which the model is validated for the intended area of use. Also, it is important that the watershed specialist help design the monitoring programs (e.g., vegetation monitoring programs) which will ultimately provide the indicator variables employed by the selected model. The specialist should be especially concerned that sampling locations are representative of important hydrologic units, that the principles of randomization, replication, and control are employed in the sampling design, and that the required cover parameters are sampled.

### Simple Lumped-Parameter Models

The most commonly used rangeland watershed models for estimating runoff, soil loss, and sediment yields are, respectively: The Soil Conservation Service (SCS) Curve Number Runoff Model, the Universal Soil Loss Equation (USLE), and the Modified Universal Soil Loss Equation (MUSLE). In addition to being useful on their own, these models are often integral components of larger system models.

#### SCS Curve Number Model

The SCS Curve Number Model (US Soil Conservation Service, 1975) is, conceptually, a very simple rainfall runoff model. The model incorporates three fundamental assumptions about the functioning of a watershed. First, it assumes that runoff does not begin upon the initiation of rainfall, but rather the watershed absorbs all rainfall up to a point. This is termed the initial rainfall abstraction. Second, the model assumes that, following the initial abstraction, the ratio of runoff to rainfall is proportional to the ratio of actual to potential watershed storage. So, the more rainfall actually stored on the watershed, the higher the proportion of rainfall which appears as streamflow. Third, the model assumes that the initial abstraction is 0.2 times the potential watershed storage. This relationship is based upon the analysis of considerable runoff data. The actual SCS runoff equation is

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \quad (1)$$

where Q is a volume runoff, and S is the potential watershed storage and P is precipitation. The SCS chose to define S in terms of a runoff curve number, CN, which ranges between 0 and 100.

$$S = \frac{1000}{CN} - 10 \quad (2)$$

Using this definition of curve number, runoff goes up as curve number goes up.

Curve number selection is generally based upon hydrologic soil group, vegetation cover, land use, hydrologic condition, and antecedent soil moisture. Curve number selection is aided by tables and graphs. Recent studies suggest that curve number selection may be aided by remote sensing (Rango, 1985), or by correlation with soil-hydraulic properties and vegetation cover.

Given a runoff volume for a given design rainstorm, the SCS Curve Number Model constructs a synthetic triangular hydrograph by defining a peak flow, a time to peak, and a recession time. The time to peak, which was determined empirically, is defined in terms of a watershed time of concentration. Since the hydrograph is a triangle, peak flow is solved trigonometrically given the triangle base dimensions and area (volume runoff).

While the SCS Curve Number model, based upon years of actual rainfall-runoff data, is both conceptually and numerically simple; it lumps many important watershed variables and is highly sensitive to curve number selection. Therefore, it must be applied carefully and its results should be evaluated with a great deal of professional judgment.

Currently, rangeland relationships between curve number and vegetation cover are developed only in a general sense (i.e., in terms of hydrologic condition). Thus, the Curve Number Model has limitations as a monitoring tool. However, it may be used to evaluate rainfall-runoff data, and to quantify the long-term effects of land management on curve number. As the model becomes validated on a site-specific basis, its utility as a planning and monitoring tool will be enhanced.

#### Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE), an empirical erosion model, computes long-term average annual soil losses from sheet and rill erosion (Wischmeier and Smith, 1978). Soil loss is calculated from Factors representing rainfall patterns, soil type, topography, vegetation cover, and management practices. Data from over 10,000 runoff and soil-loss plots, mostly located in the eastern and midwestern United States, were used to quantify each of the USLE factors. As they are defined, slope length, steepness, cover, and land management factors modify measured soil loss rates from reference plots 72.6 feet long on 9 percent slope, maintained in tilled, continuous fallow. Where reference plot data are unavailable, empirical techniques predict reference plot soil loss through correlation with soil type and rainfall characteristics.

The Universal Soil Loss Equation is

$$A = RKLSCP \quad (3)$$

where:

A is the computed soil loss expressed in tons per acre per year.

R, the rainfall and runoff factor, is the number of rainfall erosion index units for a normal year's rainfall and considers the effects of raindrop energy and maximum rainfall intensities.

K, the soil erodibility factor, is the soil loss rate per erosion index unit for a specified soil on a unit plot, which is defined as a 72.6-ft. length of uniform 9 percent slope continuously in clean-tilled fallow.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6-ft. long plot under identical conditions.

S, the slope-steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9 percent slope under identical conditions.

C, the cover and management factor, is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled, continuous fallow.

P, the support practice factor, is the ratio of soil loss with a conservation practice such as contour furrowing to that with straight-row farming up and down the slope.

USLE calculates long-term average annual soil loss caused by sheet and rill erosion from rainfall and runoff. It may be used to (1) compare existing erosion condition to a predetermined standard or "tolerance," (2) predict the effects on soil loss of planned management alternatives given knowledge of how those management alternatives affect vegetation cover and soils condition, (3) indirectly monitor the management effects over time on erosion by using site and cover data to estimate soil loss, and (4) identify important or sensitive erosion areas and quantify spatial variations in watershed erosion.

The USLE procedure has several important limitations:

- (1) The equation only estimates soil loss caused by sheet and rill erosion. It does not predict soil deposition, nor does it estimate gully or stream channel erosion, all of which are important range-land sedimentation processes.
- (2) The rainfall-runoff factor is an index of the erosive energy of rainfall and associated runoff. It does not account for the erosive forces of soil freeze-thaw, wind, or snowmelt. Wind can be an important erosive force on arid and semiarid rangelands. A procedure for estimating wind erosion is described in USDA (1975).

Snowmelt is generally not an important cause of sheet and rill erosion on most western United States' rangelands, although it may be important when soils are frozen or when rain occurs on a shallow snow-pack.

- (3) The equation has not been well validated on western rangelands and its accuracy is unknown. While relative differences in soil loss estimates should be meaningful in planning and monitoring programs, soil loss estimates used for engineering designs or economic analyses may involve a significant, though unknown degree of inaccuracy.

As a monitoring tool, USLE is sensitive to changes in vegetation type, canopy cover, and ground cover. Presently, however, rangeland cover relationships are not well developed. The goal of an ongoing program by BLM and the Agricultural Research Service is to improve the applicability of USLE to rangelands, and in particular, providing improved determinations of the Cover, "C", factor.

#### Modified Universal Soil Loss Equation

USLE (Williams, 1975) was modified to permit its application in calculating storm-period sediment yields. In its modified form, the rainfall factor in USLE is replaced by a runoff factor. The runoff factor is defined empirically in terms of total runoff volume, Q, and peak runoff rate,  $q_p$ . The Modified Universal Soil Loss Equation, MUSLE, is

$$y = 11.8 (Qq_p)^{0.56} KLSCP \quad (4)$$

where all terms are as defined above and y is sediment yield, in tons.

MUSLE, a fairly new equation, is still undergoing validation. While it shares many of the same shortcomings of USLE, preliminary validation results suggest it may be a useful predictor of sediment yields. Like USLE and the SCS Curve Number model, MUSLE is commonly a component of larger watershed systems models.

MUSLE was designed to predict storm-period sediment yields on a field scale. Longer term sediment yields from larger watersheds are often estimated using a method developed by the Pacific Southwest Inter-Agency Committee (1968).

#### Integrated Systems Models

Within the range and watershed science a few models are available and many are in the final development stages. Most models analyze surface runoff, subsurface runoff, percolation, erosion, sediment yield, plant growth, or a combination of these factors.

In range monitoring, a model's usefulness depends on the specialists' needs. Several broad areas of modeling applications include:

1. Quantify the response of a factor such as plant growth or runoff to an environmental condition.

2. Normalize a response to an "average" set of conditions.
3. Create historical response curves based on weather records or other observations.
4. Create response curves that reflect the probability of a particular occurrence (i.e., floods, low production, unacceptable erosion).
5. Improve monitoring efficiency by estimating: (a) magnitude of a response (is it within measurable limits?), (b) factors most sensitive to change, (c) influence of soils on changes, (d) sensitivity of a monitoring plan to a management action, and (e) optimum time for field data collection.
6. Provide an analysis tool to interpret monitoring data.

The specialists' knowledge of a site's complex interrelationships will dictate the use of a particular model in range and watershed monitoring. Rangeland models will never replace sound professional judgment, but they can support judgments and provide additional analysis tools. Four models, each with a great deal of promise, are described briefly below.

#### Water Resources Simulator

The Simulator for Water Resources in Rural Basins (SWRRB) model simulates hydrologic and sedimentation processes in rural basins (Arnold and Williams, 1985). SWRRB simulates daily, monthly, or yearly runoff and sediment yield on large complex basins, including routing through reservoirs, ponds, and channels.

A weather generator is included which allows the model to operate when daily precipitation and temperature data are not available. Surface runoff is generated using the SCS curve number methods, with curve number continuously corrected for daily soil moisture content. Evapotranspiration is estimated daily. Sediment yield is simulated by the MUSLE (Williams, 1975) and a sediment routing model. The model, currently available for microcomputers, has interactive data entry capabilities.

#### Erosion and Productivity Impact Calculator

The Erosion and Productivity Impact Calculator (EPIC) simulates soil loss and crop production (Williams, 1985). The model is especially useful in providing an understanding between soil-loss and nutrient-loss effects on long-term productivity. EPIC is a field-scale model with nine major components--hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, plant environment, and economics.

The hydrology component is based upon the SCS curve number method and accounts for both variable soil layer thickness and runoff from frozen soil. Both percolation, lateral subsurface flow and evapotranspiration are accounted for. The erosion component is based upon the USLE. Weather input can be simulated as the model can be run for long time periods (greater than 100 years). While EPIC was originally developed for croplands, it may be applicable to rangelands. Validation efforts on rangelands are ongoing.

## Rangeland Hydrology and Yield

The Ekalaka Rangeland Hydrology and Yield Model (ERHYM) models soil moisture, runoff, and annual herbage yield on northern Great Plains Rangelands (Wight and Neff, 1983). The model currently is being validated for broad application on rangelands. ERHYM can simulate any year's observed hydrologic and vegetation response using actual daily climate data, or it can simulate a current year's growing condition and forecast future peak standing crop. If unavailable, the model is capable of generating temperature and solar radiation data.

ERHYM separates precipitation into runoff and water available for soil-water recharge based upon the SCS curve number method. It then provides a daily accounting of soil-water content. Evaporation is calculated as a function of potential evaporation and the time since the soil was last wetted. Transpiration removes water from each soil layer based upon the potential transpiration soil-water content, root distribution, and soil temperature. Herbage yields are based upon average or potential site productivity and are modified by the ratio of actual transpiration to potential transpiration.

## Production and Utilization on Rangelands

The simulation of Production and Utilization on Rangelands (SPUR) model was developed by the Agricultural Research Service to represent state-of-the-art in rangeland ecosystem models (Wight and Springer, 1985). SPUR is a physically-based model which simulates grazing of up to seven individual plant species on up to nine range sites. The model can account for wildlife consumption, plant competition, and livestock and plant site preference.

SPUR has five basic components: (1) climate, (2) hydrology, (3) plant, (4) animal, and (5) economic. The model requires climate data that can be from historic records or generated within the model. The hydrology component is based upon the SCS curve number method, but has enhanced capability to deal with snowmelt, and water and sediment routing. The plant growth model is more sophisticated than that in ERHYM and simulates the dynamics of phytomass and nitrogen in the soil-plant system. Both a pasture-scale and basin-scale version of SPUR have been developed. The model is currently being refined and validated and is available for research applications.

## Precipitation-Runoff Modeling System

The Precipitation-Runoff Modeling System (PRMS), developed by the U.S. Geological Survey, evaluates the impacts of precipitation, climate, and land-use on surface water runoff and general small basin hydrology (Leavesley et al., 1983). The model has a modular design which allows the user to design and construct a model which meets his needs from a general library of sub-routines.

PRMS can function as either a lumped or distributed parameter model and can simulate both mean-daily and stormflow hydrographs. The model is applied to small watersheds which have been divided into hydrologic response units (HRUs) based upon gross basin characteristics such as slope, aspect, soils, and vegetation. A water and energy balance is then maintained for each HRU. Streamflow is generated by surface, subsurface (interflow), and ground water

flow components, and then routed through the channel system. Net precipitation is partitioned into surface runoff using a form of the Green and Ampt infiltration equation. Snowmelt is computed by an energy balance method. Soil-water can be evaporated, transpired, or routed--either to the streams or to a ground water zone.

The model is highly physically based and is very data-intensive. As a result, it generally requires calibrating to individual watersheds. Calibration and parameter optimization have been performed on a large number of rangeland watersheds in U.S. coal regions.

## IX. STATISTICAL CONSIDERATIONS IN WATERSHED MONITORING

Controls, replication, and randomization are important considerations in watershed monitoring plans and all are necessary to evaluate the effect of a management action.

### Controls

Controls are necessary to attribute a detected change (or lack thereof) to a management action. If the management action and control areas are located so that the management action is the only difference between two areas, then any change can be attributed to the management action rather than to a pre-existing difference between the two areas. If an area receiving a management action changed significantly over time, it will be difficult to prove that the management action caused the change unless a comparable control area was monitored.

### Replication

Statistical tests are based on variability. Statistical tests compute the variability within a group of measurements and compare this "within" variability to the variability between groups of measurements. If the variability between groups is much larger than the variability within groups (as measured by an F test), the groups are significantly different.

Thus, at least two independent plots, samples, or observations per management action and per control area are required to compute the within group variability. It is not acceptable to use one plot or sample and measure it year after year. The years are not replications, but are repeated observations on the same plot. Statistics books refer to these as repeated measures or nested designs (Winer, 1971). If only one plot, sample, or observation is used, statistical methods cannot be applied to the data analysis.

The number of samples or plots required to detect differences between management action and control areas depends upon the computed variance.

The F test, or variance ratio test, tests whether a difference between two or more mean values, such as the mean sediment yield for an enclosure and a control area, is statistically significant. As sample size increases, the tabulated F values, which must be exceeded for a given level of significance to apply, decrease.

Because both the variance and tabled F values decrease rapidly as the number of samples or plots increase from two to four, even one more sample or plot than the minimum of two will result in a much more sensitive statistical test. If the difference between the management action and control areas is large, then a small number of samples or plots will detect the difference. However, if the measured difference is small, then a large number of samples will be needed to detect a difference. Most statistics books, such as Sokal and Rohlf (1969) or Snedecor and Cochran (1976) give formulas to estimate the sample size needed to detect a difference between two means.



## Randomization

The purpose of randomization is to remove bias. Randomization gives each potential plot location an equal chance of selection. The area included in the randomization process is the same area where any conclusions will apply. If the area where the management action will be applied is chosen rather than randomized, conclusions will apply only to that particular area, and not to any surrounding area, no matter how similar that surrounding area might be.

If, within a grazed pasture and within an ungrazed pasture, erosion plot locations are randomly selected from among all the possible plot locations with a slope of 2 to 3 percent on the xyz soil, then conclusions will apply to all areas within the grazed and ungrazed pastures with 2 to 3 percent slopes on the xyz soil. If, however, the grazed and ungrazed pastures were randomly chosen from among all pastures within a larger allotment, then conclusions will apply to all parts of the allotment with 2 to 3 percent slopes on the xyz soil.

When randomization is done over larger areas, the variability increases as more diverse areas are included within the randomization area. If the number of replications is small, i.e., two or three, then sites should be very similar so that the variability will be as small as possible.

Two packaged statistical programs, SPSS and BMDP, are available as batch programs on BLM's Honeywell DPS-8 and will perform all these analyses. Statpack, an interactive statistical package, will perform some of the analyses.

## X. SAMPLE DESIGN AND DATA ANALYSIS

### Sample Designs

Plot studies should be designed with controls, plots should be randomly located, and samples should be replicated to provide a desired level of statistical significance to the data analysis. A thorough discussion of sampling designs for upslope plot studies is provided in Jackson, et al. (1985).

Instream studies are also best designed with a statistical control so that paired-sample analyses can be performed on the data. Ponce (1981) provides a thorough discussion of sampling designs for instream water quality studies.

### Data Analysis

The sampling design generally dictates the data analysis methods which can be used. Most upslope or instream studies are analyzed using one or more of four common statistical methods: T-tests, Analysis of Variance (ANOVA), Regression Analysis (including trend analysis), and Covariance Analysis. Each of these methods is described below.

Three major assumptions shared by the four methods are independence of observations, normality of the underlying distributions, and equality of within group variances. Independence is the most important and the most often violated criterion. Typically, violation of the independence assumption overestimates the statistical significance of change and/or differences. Violation of the normality and equality of variance assumptions can often be corrected by transforming the data and when not corrected, tends to underestimate the significance of statistical tests.

Time-series analyses can also be used to fit and forecast hydrologic data, and are described below. A time series approach to analyze hydrologic data, which is often correlated with time, is generally warranted since the independence of observations assumption is relaxed. Presently, time series analysis is not often used in hydrologic analyses, though the recent availability of easily used computer programs may encourage its use.

### T-test

A T-test assesses the significance of a difference between two sample means. One form of the test, often called a two-sample T-test, is used with independent samples while another form of the test is used with paired or dependent samples. With an independent sample, observations or measurements are classified into two groups and a test of mean differences is performed. If the observations within a sample are paired or correlated, one of the sets of observations is subtracted, pairwise, from the other and resulting values are tested for a difference from zero.

The paired T-test is quite sensitive, since pairing removes outside influences on the measured variables. If the total number of observations is very small, i.e., less than eight, a paired test is not as sensitive as a two-sample test.

## Analysis of Variance

Analysis of Variance (ANOVA) assesses the effects of one or more factors upon a continuous dependent variable. A one-way ANOVA, which has only one factor, is merely an extension of the T-test to more than two groups. Typical watershed monitoring factors are grazing intensity, season of the year, soil type, and vegetation cover, while total storm runoff, sediment yield, and TDS are common dependent variables.

The most important special class of designs for watershed monitoring is that class which has repeated testing or measuring of the same object or individual, such as daily readings from a stream gage or several years' runoff values from erosion plots. The repeated measure designs also assess the significance of a trend over time.

## Regression Analysis

Regression analysis predicts one variable (the dependent variable) in terms of one or more other variables (the independent variables). The coefficient of multiple determination,  $r^2$ , measures the prediction accuracy and strength of the linear association.

Regression analysis can be performed upon a fixed number of independent variables, or a stepwise technique which allows variables into the regression equation sequentially, depending on their predicting ability, can be used.

## Covariance Analysis

Covariance analysis combines the features of analysis of variance and regression, and is often used to determine if one regression relationship is different from another. The analysis has one continuous dependent variable, but the independent variables include both the types described above under regression and analysis of variance. The dependent variable is adjusted by the "regression type" independent variables before an ANOVA assesses the influence of the "ANOVA type" independent variables. The "regression type" independent variables must not influence the "ANOVA type" independent variables, but should influence the dependent variable directly.

In watershed monitoring, the main use of this statistical technique is correcting for uncontrolled influences such as rainfall. Properly used, this technique increases the sensitivity of an analysis of variance.

## Time Series

Time series analysis characterizes the way measurements, made at equidistant points, vary over time. The measurements may be correlated, with the correlation between measurements depending on the time interval separating them. The analysis allows for the presence of a trend in the data. Generally, the three steps to model a time series are: (1) identify a tentative model, (2) estimate the parameters and examine diagnostic statistics and plots, and (3) forecast using the model, if it is deemed acceptable (SPSS, Inc., 1983).

## XI. INTERPRETATIONS FROM MONITORING DATA

The purpose of monitoring is to determine whether or not management objectives are being achieved by implementing land use management plans. Therefore, the final and key step in watershed monitoring is to ensure that not only the results of monitoring programs, but interpretations, analyses, and alternative recommendations are fed back into the planning system. Even when it is determined that management objectives are being met, the results of a monitoring program may indicate that management modifications are required, or even that modifications in the original watershed management objectives should be considered.

Well planned and well-implemented monitoring programs will do more than meet monitoring objectives. They will enhance our understanding of both natural systems and the effects of management prescriptions. As such, they will provide additional, useful information to all steps of the resource management planning process.

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